REMARKS

I.   Claim Rejections 35 U.S.C. § 102 or 35 U.S.C. § 103(a)

In the Office Action dated August 18, 2006, the Examiner rejected claims 21-41 under 35 U.S.C 102(b) as being anticipated by Widrow (U.S. Patent No. 3,222,654).

The Examiner argued that Widrow teaches a logic circuit and electrolytic memory element (arguing "perceptron") illustrated in FIGS. 1 and 2 and described in the text of Widrow, referring specifically to Widrow, C1:10-14; C2:40-48; and C3:18-28. The Examiner stated that other related text of Widrow are identified in prior office actions.

The Examiner argued that the Applicant has disclosed a physical. neural network that achieves functionality by the process of applying an electric field across two electrodes that are immersed in a liquid dielectric solvent containing nanoconductors. The Examiner further asserted that it is through the process of applying the electric field that the nanoconductors align to form physical neural network nanoconnectors between pre-synaptic and post-synaptic electrodes. The Examiner argued that such is a product by process and a neural network developed by the process of applying the electric field.

The mere application of an electric field is not enough to create Applicant's neural network. There are many other factors that come into play, which are not taught, anticipated or suggested by Widrow. One of these factors is the use of a dielectric medium in which Applicant's nanoconductors are located as a part of the overall physical neural network. As the Examiner indicates above, Widrow refers to an electrolytic memory element. The key word here is electrolytic, because in fact, Widrow is based on electrolytic principals, while Applicant's invention is based on the use of a dielectric medium. This a significant difference, particularly in light of

the fact that there is simply no teaching, suggestion or disclosure in Widrow of a dielectric medium in which nanoconductors are disposed.

An electrolytic medium such as that of Widrow is not a dielectric medium: one exists for the movement of ions to promote electrical conduction (electrolytic); the other is used specifically for its properties of canceling electric fields, and more importantly to the Applicant's invention, for inhibiting electrical conduction (i.e., dielectric). An electrolytic medium involves the use of an electrolyte and not a dielectric. Widrow provides no teaching, suggestion or disclosure of the use of such a dielectric medium as taught by Applicant's invention.

An electrolyte is a substance containing free ions which behaves as an electrically conductive medium. A dielectric, on the other hand, is basically an electrical insulator, and constitutes a substance that is highly resistant to electric current. Unlike an electrolyte, a dielectric tends to concentrate an applied electric field within itself. As the dielectric interacts with the applied electric field, charges are redistributed within the atoms or molecules of the dielectric. This redistribution alters the shape of the applied electric field both inside and in the region near the dielectric material. It is this process, when taken with the affects of nanoparticles also displaying a dielectric behavior, which causes a dipole-induced force to attract the particles to the connection gap. For example, refer to paragraph of [00103] of Applicant's invention where it is stated that "...The only general requirements for the conducting material utilized to configure the nanoconductors are that such conducting material must conduct electricity, and a dipole should preferably be induced in the material when in the presence of an electric field."

In order to further understand the significant differences between Applicant's invention and the Widrow device, the Applicant believes that is would be helpful to outline the basic components and workings of Applicant's invention. Applicant's invention essentially utilizes 7 basic circuit elements and functions, which can be broken down as follows:

1. Voltage source (AC or DC)
2. Pre-synaptic and post-synaptic electrodes (any conductive substance)
3. Non-electrically conductive viscous solution (i.e., dielectric solution)
4. Electrically conductive (preferably charge-neutral) nanoparticles/nanoconductors.
5. Two-terminal device
6. Dielectrophoresis
7. Non-permanent interconnect

An illustrative example of Applicant's invention is shown in the figure below.
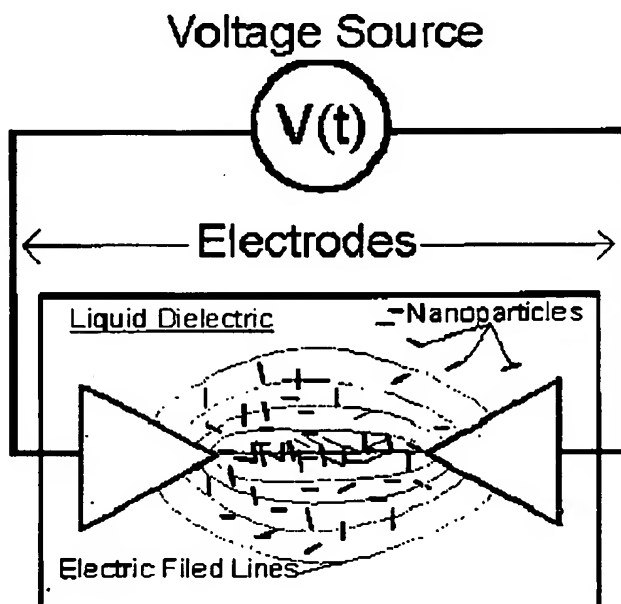

Figure 1

The operation of Applicant's Invention is as follows. Pre-synaptic and post-synaptic electrodes (shown as gold/yellow in Figure above) are charged with a voltage source. This voltage may be DC or AC, though AC is preferred. The applied voltage generates an electric field between the electrodes. The region between the electrodes is comprised of a liquid dielectric and nanoparticles. The inhomogeneous

Page 12 of 27
SERIAL NO. 10/748,546

electric field generates a dipole in the nanoparticles. The dipole induced force, which results from the interaction of the applied electric field with the dipole, draws the nanoparticles into the region between the electrodes. The accumulation of nanoparticles between the electrodes facilitates the electrical conduction between the electrodes. The physical process of moving particles with a dipole-induced force is generally referred to as dielectrophoresis or "DEP". In fact, Applicant teaches the use of DEP at Applicant's paragraph [00276] where Applicant states:

"...The fibers can grow in the direction of the other electrode until the gap is bridged, with the wires remaining in contact after the electric field is removed. The nanowire growth is caused by particle aggregation at the tip of the fibers, thereby extending them toward the opposite electrode. The tip of the growing nanowire can create local electric fields of high intensity and gradient, giving rise to a <u>dielectrophoretic</u> force, which causes the aggregation."

The use of such a dielectrophoretic force (i.e., DEP) is also taught at Applicant's paragraph [00338] as follows:

For example, if the desired output depicted in FIG. 43 is "low" and the actual output is "high", then the connection strength can be decreased from "high input neurons". Similarly, if the desired output is high and the actual output is low the connection strength can be increased from "high input neurons". If the desired output is high and the actual output is high, then no action is required. Similarly, if the desired output is low and the actual output is low, then no action is required. In order to increase the connection strength, an increased field gradient can be applied across the connection gap (i.e., containing nanoparticles in solution) or the frequency can be altered across the connections thereof, whether "up" or "down". To weaken the connection strength, the connection(s) can be charged by raising the pre- and post-synaptic electrodes to a high voltage. Because the <u>dielectrophoretic</u> force responsible for particle chaining is frequency-dependant, the electrical frequency across the pre- and post-synaptic electrode can also be altered in order to weaken the connection strength. Thus, amplifiers 4326 and 4324 can be regarded as a general mechanism to provide a feedback signal, either through a steady-state voltage signal or an increased or decreased frequency.

A short tutorial of DEP is provided below.

Dielectrophoresis

The use of nanoparticles (e.g., nanoconductors) in a dielectric solution and exposed to electric fields as taught by Applicant's invention is based on the scientific principals of dielectrophoresis (also referred to as "DEP"). The field of dielectrophoresis was first defined and described by Pohl in his book entitled "Dielectrophoresis: The Behavior of Neutral Matter in Nonuniform Electric Fields" published by Cambridge University Press, Cambridge UK, 1978. The Applicant is not submitting a copy of this text as it is out of print and also is the defining work of the field. There are numerous other texts and web-based material, which is more recent and freely available. The important fact here is that the field of dielectrophoresis was not conceived until 1978, more than twelve years after the date of the Widrow patent (1965).

An explanation of the concept of dielectrophoresis was presented in the following article, which was submitted with Applicant's original Information Disclosure Statement (IDS).

Hermanson et al., "Dielectrophoretic Assembly of Electrically Functional Microwires from Nanoparticle Suspensions," Materials Science, Vol. 294, No. 5544, Issue of 2 Nov 2001, pp. 1082-1086

The Applicant invites the Examiner to review this paper, which should already be included in the patent application file wrapper. The concept of dielectrophoresis is additionally discussed in the following paper, which was also included with Applicant's original IDS submission:

Smith et al., "Electric-field assisted assembly and alignment of metallic nanowires," Applied Physics Letters, Vol. 77, No. 9, 28 August 2000, pp. 1399-1401

In order to understand Applicant's invention, however, a short discussion of the concept of dielectrophoresis would be helpful.

When a particle is suspended in a dielectric liquid medium and subjected to an electric field, the electric field induces a polarization in the particle. If the field is homogeneous, the induced dipole aligns in the direction of the field. If the field is inhomogeneous, the particle will feel a force. The direction of the force is determined by the dielectric properties of the particle and suspension. If the particle is more polarizable than the surrounding medium, the particle will feel a force in the direction of increasing field gradient, which is termed **positive DEP** (pDEP). On the other hand, **negative DEP** (nDEP) results when the medium is more polarizable than the particle. At low frequencies, charge accumulation at the particle/medium boundary contributes to the induced dipole, which is referred to as the **Maxwell-Wagner Interfacial Polarization** and is a function of the particle and medium conductivities. As the frequency is increased, this term of the polarization has increasingly less of an effect, as mobile charges do not have time to move an appreciable distance. For the case of a spherical particle, the time-averaged DEP force is given by:

$$\vec{F}_{dep} = 2\pi r^3 \varepsilon_0 \varepsilon_m \, \text{Re}\left[\frac{\varepsilon_p^* - \varepsilon_m^*}{\varepsilon_p^* + 2\varepsilon_m^*}\right] \nabla E^2$$

Equation 1

For any geometry other than a sphere or ellipsoid, an analytical derivation of the DEP force is not trivial, and the applicability of Equation 1 requires the particle radius to be small compared to the changes in the gradient of the energy density (∇E^2). This is certainly not the case for Applicant's synapse geometries, as the nanoparticle will be of equal magnitude to the inter-electrode spacing. For the case of coplanar electrodes, finite element simulation has found that the maximum DEP force occurs when the particle radius is on the same order as the electrode width. A general conclusion is that the force calculated from Equation 1 will give an

underestimate of about 20%, as the equation does not include higher-order moments that become increasingly important for large bead sizes.

It is evident from Equation 1 that the DEP force is dependant on real part of the **Clausius-Mossotti (CM) Factor**

$$\frac{\varepsilon_p^* - \varepsilon_m^*}{\varepsilon_p^* + 2\varepsilon_m^*}$$

Equation 2

The value of the CM factor determines the sign of the force. For positive values, the force is directed along the direction of maximum field gradient. The CM factor is determined by the particle and mediums complex permittivity, which can be expressed as,

$$\varepsilon^* = \varepsilon - \frac{\sigma}{\omega}i$$

Equation 3

where σ is the conductivity of the material. Equation 3 warrants special attention. The relative permittivity and conductivity of the bead and the medium determines a cross over frequency, where the DEP force transitions from positive DEP to negative DEP. This can be seen in Figure 5 below for latex beads in methanol.
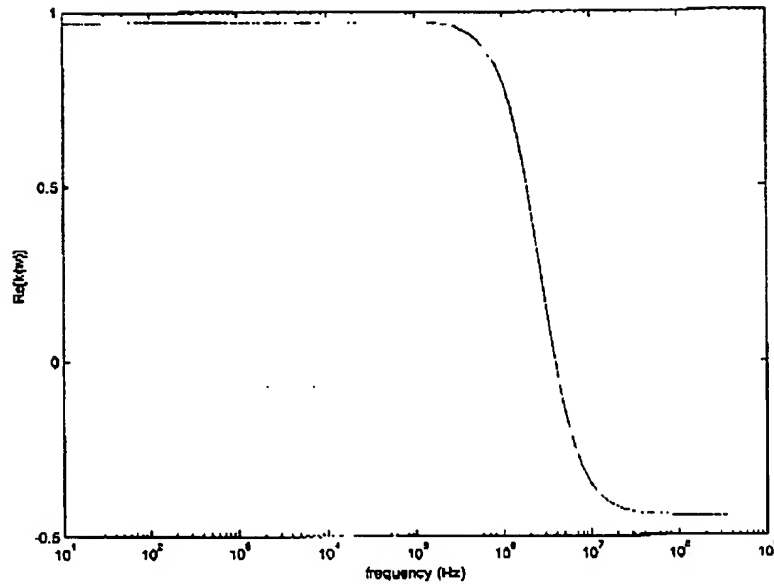
Figure 5

Real Part of the Clausius-Mossotti Factor, the frequency-dependant term in **Equation 1**, showing the cross-over between positive and negative DEP

The transition from positive DEP to negative DEP is dependant on the conductivity of the bead and medium. The real part of the CM factor is given by:

$$Re[CM] = \left[\frac{\left(\varepsilon_p - \varepsilon_m\right)\left(\varepsilon_p + 2\varepsilon_m\right) - \frac{1}{\omega^2}\left(\sigma_m - \sigma_p\right)\left(\sigma_m + \sigma_p\right)}{\left(\varepsilon_p + 2\varepsilon_m\right)^2 + \frac{1}{\omega^2}\left(\sigma_m + \sigma_p\right)^2} \right]$$

Equation 4

Page 17 of 27
SERIAL NO. 10/748,546

One can see that as the frequency is increased, the conductivity becomes increasingly insignificant. The crossover frequency can be found from Equation 4 and is given by:

$$\omega = \sqrt{\frac{(\sigma_m - \sigma_p)(\sigma_m + \sigma_p)}{(\varepsilon_p - \varepsilon_m)(\varepsilon_p + 2\varepsilon_m)}}$$

Equation 5

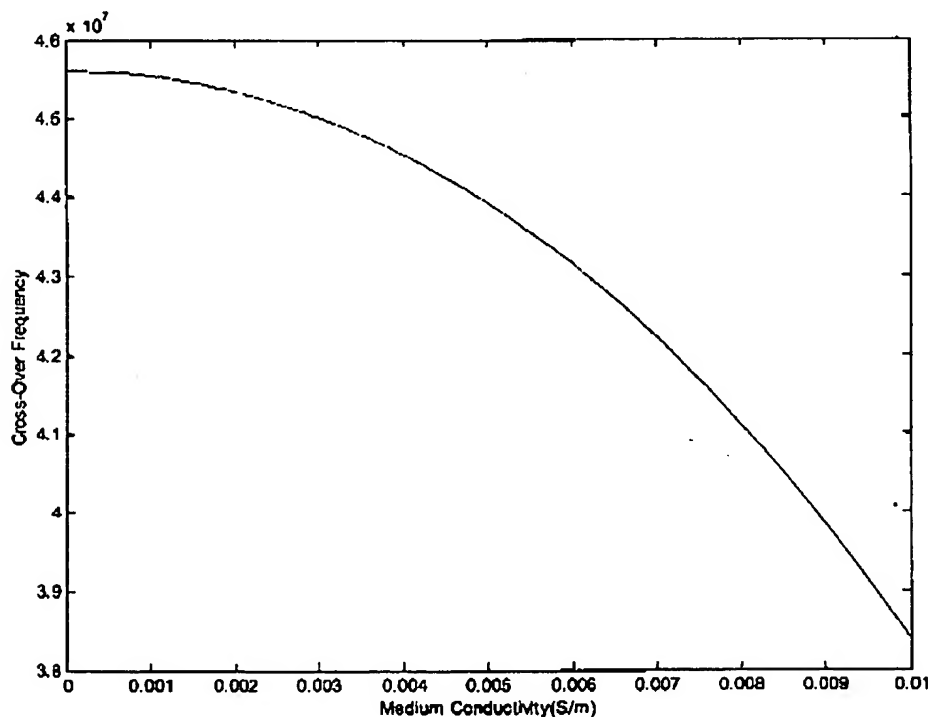Figure 6 shows the cross over frequency plotted against the medium conductivity.

Figure 6

Cross Over Frequency vs. Medium Conductivity for Latex Beads

Page 18 of 27
SERIAL NO. 10/748,546

Applicant's invention therefore uses the phenomenon of positive DEP and negative DEP as a mechanism for both attracting and repelling particles from an electrode gap. This provides the ability to both strengthen and weaken one or more synaptic components, such as those described in Applicant's invention. As in almost all physical models, there is the first-order theory, and then there are the second order effects. Some of these effects included variations in polarizibility from non-spherical particles and low-frequency charge accumulation and a resulting field cancellation, among others.

In summary, the use of a dielectric medium (not an electrolyte) as taught by Applicant's invention is based on dielectrophoresis. Such features are not taught, suggested or disclosed by Widrow. In particular, there is no teaching or suggestion of a dielectric medium for growing nanoconnections at Widrow, C1:10-14; C2:40-48; and C3:18-28, which was cited by the Examiner as a basis for the rejection to claims 21-41. In fact, Widrow at C1:10-14 refers to logic circuits and memory elements, but provides for no teaching and/or disclosure of a dielectric medium. C2:40-48 also provides for no teaching and/or disclosure of a dielectric medium, but instead refers only to various logic circuits in Widrow's figures. Finally, C3:18-28 of Widrow cited by the Examiner refers only to components of an adaptive logic circuit, but again provides not hint or disclosure of the use of a dielectric medium as taught by Applicant's invention. The lack in Widrow of the teaching or disclosure of a critical component such as a dielectric medium is very significant.

In addition to the lack of a disclosure, teaching and/or suggestion in Widrow of the use of a dielectric medium and nanoconductors disposed in such a dielectric medium, Widrow also teaches a device based on the concept of electroplating. (See, for example, Col. 2, lines 13-16 and Col. 4, lines 34-55 of Widrow). The Widrow apparatus is a chemical device whose foundation is the process of electroplating. The use of electroplating is an <u>electrochemical</u> process, which stands in stark contrast to Applicant's device, which is based on an <u>electromechanical</u>

process/system (i.e., nanoconductors in a dielectric medium and subject to a dielectrophoretic force).

The Widrow devices utilizes the electrochemical process of electroplating to achieve its operations. The chemical process is fundamental to its operation and described in detail throughout the Widrow patent and stated as a limiting aspect of the invention in every single claim. For example, claim 1 of Widrow refers repeatedly to the use of an electrolyte and electroplating.

By stark contrast, the Applicant's invention is **electromechanical**. No chemical bonds are broken nor made during device operation. The dipole-induced force described earlier with respect to Applicant's invention acts to accumulate particles between electrodes to facilitate electrical conduction.

Widrow simply fails to teach the use of a dielectrophoretic force, a dielectric medium and a plurality of molecular conductors disposed in such a dielectric medium. The device of Widrow is limited to the use of the electrochemical process/apparatus of electroplating/electrolytes. The Applicant's invention may use nanoconductors such as carbon nanotubes, gold nanowires, gold nanoparticles, latex spheres, DNA, etc. In the Applicant's invention, an electric field affects such nanoparticles by inducing a dipole force. That is, the dipole is induced in the nanoparticle/nanoconductor, which in turn causes a force towards regions of high field gradient such as the connection gap described and claimed by Applicant. Note that the direction of a dipole induced force is not necessarily the direction of the applied electric field. The electrical conduction between electrodes that form the electrode gap is regulated by the presence of nanoparticles (i.e., nanoconductors) at or near the connection gap. This process is thus electromechanical.

Another significant difference between Widrow and Applicant's invention is that Widrow is a three-terminal device and Applicant's invention is a two-terminal device. See, for example, FIG. 16 of Widrow, where a three-terminal configuration is illustrated. The difference between a three-terminal device and a two-terminal

device is significant in building large adaptive systems. In order to assist the Examiner in appreciating this difference, we provide the following discussion. Imagine two electrical devices – device 1 and device 2. Device 1 is composed of three-terminals, which we will call terminals A, B, C. The conductance between terminal A and C is a function of the voltage of terminal B. In other words, by applying a certain voltage to terminal B, we may increase the conductance between terminals A and C. By applying an opposite voltage, we may weaken the conductance between terminals A and C. Now, picture the second device, device 2, which only has two terminals, which we will refer to as A and C. The conductance between terminals A and C of device 2 is a function of the accumulation of voltage over time between terminals A and C. Now, to make clear how these two devices are used, we can say the following: for device 1, the conductance between terminals A and C is a function of what we do to terminal B; for device 2, the conductance between terminals A and C of device 2 is a function of how we use terminals A and C. Device 2 implies adaptability whereas device 1 implies set-ability.

To put this into a practical perspective, let us assume that device 1 and device 2 occupy equal volumes. Let us further assume that we are trying to build a highly interconnected system on the order of what we see in biological systems (e.g., brains). In this case, we will require on the order of approximately 1 quadrillion (i.e., a million billion) devices, where such devices are equivalent to a synaptic junction. Disregarding the volume taken up by neurons and the wires connecting the synapses, at a bare minimum we know that the volume occupied by these devices would be a 1 quadrillion multiple of the device volume. Now consider device 1. Because of the three terminal nature of device 1, the device cannot be operated as a standalone adaptive element. Rather, we must now create a second circuit such that this circuit takes as an input the voltages on terminals A and C of device 1 and outputs an appropriate voltage onto the terminal B of device 1. The

volume of the device 1 implementation is now much greater because it includes not only the adaptive element but also the circuit for controlling the adaptive element. So, at a bare minimum, in terms of volume occupied and assuming both devices do indeed occupy the same volume, we can say that device 2 system implementation occupies at least half the volume of the device 1 system implementation. Now consider that device 1, which is operationally equivalent to the Widrow device has a dimension on the order of 1 cm and that the Applicant's invention has a dimension on the order of, for example, 50 nanometers.

This three-terminal versus two-terminal difference can be applied to the dimensions provided by Widrow himself. Column 4, lines 59-61 of Widrow indicates that the Widrow substrate is 2 ¾ inches long. Assuming that the Widrow device occupies 1 cubic centimeter, then a system with 1 quadrillion of these Widrow elements would occupy roughly 1 cubic kilometer, which to put in perspective is about the size of a small mountain. But this is only for Widrow's synapse. To take into account the circuitry required to implement adaptability as discussed above, we would need at least twice this volume.

Now, consider the Applicant's invention, which is based on nanoscale device dimensions. Assuming, for example, that the Applicant's device is around 100 nanometers by 100 nanometers by 10 nanometers, then the volume occupied by 1 quadrillion of Applicant's two-terminal synapses is 10 cm^3, which is roughly the size of a human brain.

There can be no doubt that the Applicant's use of a two-terminal configuration (which is not taught, disclosed or suggested by Widrow) instead of a three-terminal invention (which is taught by Widrow) is a significant improvement over Widrow and a fundamental difference between the two devices.

Another significant difference between Applicant's invention and that of Widrow is the lack of teaching of a "liquid state machine" by Widrow. The Applicant's specification indicates at paragraph [0028] indicates the following:

Another type of neural network, which has been proposed, is known as a liquid state machine (LMS). A non-limiting and non-essential example of an LMS is disclosed in "Computational Models for Generic Cortical Microcircuits" by Wolfgang Maass, et al., Institute for Theoretical Computer Science, Technische Universitaet Graz, Graz, Austria, June 10, 1003. Note that the aforementioned Maass et al reference is referred to herein for general edification and background purposes only. It is believed that liquid state machines have not been implemented in the context of physical neural networks configured based on nanotechnology. A need thus exists for such devices, including methods and systems thereof.

The Applicant refers to this section of Applicant's specification in order to make two points. First, a liquid state machine is a very particular type of neural network. Second, this type of neural network has only been implemented to date in the context of software simulations such as that disclosed in the Wolfgang Maass reference mentioned above, and not in an actual physical neural network, that si, of course, until the conception of Applicant's invention. Applicant goes on to describe the workings of Applicant's liquid state machine in paragraphs [00328] and [00329] of Applicant's specification as follows:

FIG. 39 illustrates a system 3900 of interconnected neural circuitry referred to in the art as a Liquid State Machine, which can be adapted for use in accordance with an alternative embodiment of the present invention. Physical neural network 3900 thus comprises a Knowm™ enabled liquid state machine. System 3900 generally describes a neural network learning mechanism which can be applied to a physical neural network formed utilizing nanotechnology, as described herein. Such a network generally consists of two or more distinct neural modules. Inputs are presented to the first module, referred to as a Liquid State Machine or LSM. The LSM is generally a randomly connected network of neural circuits. Although the connections may be random, this is not always the case. Generally, the exact nature of the connections are not as important as the statistics of the connection, such as the amount of interconnectivity. However such a LSM is connected, its sole purpose is to provide what is referred to in the art as an "analog fading memory". In a liquid state machine, memory tends to fade, similar to the fading of ripples associated with liquid, such as water, as a result of input (e.g., a rock thrown in a pond) to the liquid or water at various times and locations thereof.

The LSM can store, via patterns of neural activations, its recent past history. Other types of neural circuits can be utilized to extract the "state" of the LSM. A state-extracting neural circuit can be accomplished by a very simple learning neuron, such as, for example, a perceptron. Such perceptrons can adjust their synaptic weights so as to produce a desired

output. Such perceptrons can be referred to as a "read-out" neuron. The exact rule that the read-out neurons utilize may vary, but in general such read-out neurons can form a simple linear mapping between the neural circuits within the LSM and the read-out neuron output.

Based on the foregoing and a thorough reading of Applicant's specification it can be appreciated that a liquid state machine or LSM of Applicant's invention, in order to function, includes the use of read-out neurons, a linear mapping between neural circuits and perceptrons that can adjust their synaptic weights to as to produce a desired output. Additionally, in an LSM memory tends to fade, similar to the fading of ripples associated with liquid, such as water, as a result of input (e.g., a rock thrown in a pond) to the liquid or water at various times and locations thereof. This does not mean of course that "water" is an element of a liquid state machine. The reference to "liquid" in the name "liquid state machine" is only a metaphor for how the device functions. That is, the word liquid in the name comes from the analogy drawn to dropping a stone into a still body of water or other liquid. The falling stone will generate ripples in the liquid. The input (motion of the falling stone) has been converted into a spatio-temporal pattern of liquid displacement (ripples).

Applicant believes that the attempt by the Examiner to compare the liquid dielectric of the Applicant's invention to the "liquid" of the liquid-state machine is a result of a lack of understanding of what a "liquid state machine" is. An LSM can be thought of as a decaying dynamic memory. In this way, it is not waves of a liquid that are decaying. It is neural signals in feedback loops within a neural network. In the system described by Applicant's invention, the dynamic decaying memory are the electrical signals being passed between neural circuits through the Applicant's synaptic device element. Widrow, on the other hand, does not teach or disclose this, but describes only a synaptic device element, which bares no similarity to the synaptic device element described by the Applicant.

Page 24 of 27
SERIAL NO. 10/748,546

A liquid state machine in the past has been presented by various researchers and software scientists as a computational construct and includes a large collection of units (called *nodes*, or *neurons*). Each node receives time varying input from external sources (the inputs) as well as other nodes. Nodes are randomly connected to each other. The recurrent nature of the connections turns the time varying input into a spatio-temporal pattern of activations in the network nodes. The spatio-temporal patterns of activation are read out by linear discriminant units. The soup of recurrently connected nodes will end up computing a large variety of nonlinear functions on the input. It is important to keep in mind, however, that such components and functions of a liquid state machine have only been presented in the context of neural network software simulations. Applicant believes that prior to Applicant's invention there has not been any prior art, which teaches, suggests or discloses an actual physical neural network (not software) that is an LSM.

Given this description of a liquid state machine, which is taught by Applicant's invention, it is difficult to identify the workings of a liquid state machine in the Widrow reference. It is also difficult to see how Widrow teaches, discloses or even suggests an LSM. For a general overview of an LSM, the Applicant invites the Examiner review the following document, which was discussed in the background section of Applicant's specification:

Wolfgang Maass, et al., "Computational Models for Generic Cortical Microcircuits";Institute for Theoretical Computer Science, Technische Universitaet Graz; Graz, Austria, June 10, 2003; pp. 1-26

Applicant believes that the idea of an LSM was not developed until the late 1990's by Wolfgang Maass. Thus, the idea of an LSM was not even available at the time Widrow was issued (1965).

In a previous office action, the Examiner cited Widrow, C4:34-55 and argued that this citation shows an LSM. A review of C4:34-44 indicates that this citation provides no teaching, suggestion, or disclosure of an LSM. Instead, C4:34-44

simply refers to an electroplating device/process. Electroplating has nothing to do with an LSM. Again, keep in mind that the word "liquid" in LSM is simply a metaphor for the functioning of an LSM and has nothing to do with the fact that the dielectric may or may not be implemented in the context of a liquid dielectric solution. It is interesting to note that the paragraph following C4:34-44 of Widrow also refers to the use of electrolytes and not a dielectric medium, which again only proves the point that Widrow provides no teaching for the Applicant's claim limitations of a dielectric medium and an LSM.
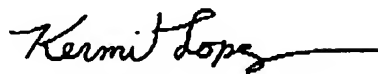
Based on the foregoing, the Applicant submits that the rejection to claims 21-41 under 35 U.S.C 102(b) as being anticipated by Widrow (U.S. Patent No. 3,222,654) has been traversed. The Applicant therefore respectfully requests withdrawal of the rejection to claims 21-41.

III. Conclusion

In view of the foregoing discussion, the Applicant has responded to each and every rejection of the Official Action. The Applicant has clarified the structural distinctions of the present invention via such amendments. Applicant respectfully requests the withdrawal of the rejections based on the preceding remarks. Reconsideration and allowance of Applicant's application is also respectfully solicited.

Should there be any outstanding matters that need to be resolved, the Examiner is respectfully requested to contact the undersigned representative to conduct an interview in an effort to expedite prosecution in connection with the present application.

Respectfully submitted,

Dated: November 29, 2006

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